# Precise temperature control for growth of silicon crystals*

S. P. Lee, J. T. Lue, Y. T. Yang, and H. Y. Yu

*Department of Physics, National Tsing Hua University, Hsinchu, Taiwan, Republic of China*

(Received 10 July 1975; in final form, 15 September 1975)

An automatic temperature controller for a three-phase, grid-controlled induction furnace, which can maintain the oven temperature at the silicon melting point with a stability of ±0.4°C for 2 h of operation, has been described.

Most Lepel (250 to 450 kc/sec) kilocycle frequency generators (e.g., T10-3KC) are equipped with a manually operated thyratron power control. By changing the phases between the grids and the plates of the thyratrons, a stepless control to regulate the power output from practically zero to maximum can be obtained. The controlling circuit is shown in Fig. 1. The three-phase 220 V ac power lines coupling with two ΔY transformers would give two secondary voltages. One is for the high voltage power supplies of the thyratron plates of the bridge rectifier, which consists of three thyratrons and three mercury diodes. The other, via another ΔY transformer, provides the grid input signal. The phase differences between the grids and the plates of the thyratrons are controlled by three 5 Ω potentiometers $R_1$, $R_2$, and $R_3$. The dc biases of the thyratrons are obtained by the 1 MΩ resistors across the phase B thyratron.

When the three phase shifters are all at zero resistance, the plate voltage $V_{A_1C_1}$, $V_{A_1B_1}$, $V_{B_1A_1}$ and the grid voltage $V_{A_4F}$, $V_{C_4F}$, $V_{B_4F}$ are in opposite phases, respectively; therefore all these tubes are unable to conduct. Increasing the three resistances of the phase shifters would shift $V_{A_4F}$, $V_{B_4F}$, and $V_{C_4F}$. These small changes of the phases of the grids and plates would ignite the thyratrons earlier.

The nature of the automatic phase control is shown in Fig. 2, where the three 3.3 Ω shunting resistors across $A_2A_3$, $B_2B_3$, and $C_2C_3$ would reduce the resistances wherein the silicon controlled rectifiers (SCR's) are conducting. This configuration operates the suppression mode. Firing the SCR's would lower the temperature, or the temperature set by the manually controlled phase shifter would be slightly higher than the desired oven temperature (which has been preset on the dial of the automatic temperature controller) in order to obtain the automatic temperature control. The signal from the temperature sensor is amplified through an operational amplifier. This amplified dc level is added to the $V_{A_2}$, $V_{B_2}$, and $V_{C_2}$ line voltages, and is sent into the triggering circuits producing a pulse when these signals are negative-going across zero. These pulse signals passing through the trigger transformers fire the SCR's. If the oven temperature is higher than the preset value, the time for negative-going zero crossing would occur earlier, firing the SCR's earlier at each ac cycle. The firing of the SCR's has the effect of lowering the resistances of the phase shifters, increasing the phase differences between the grids and plates of the thyratrons, and consequently reducing the power output. If the oven temperature is lower than the preset value, the time for negative-going zero crossing would occur later, firing the SCR's after the thyratron has been fired and giving no contribution to suppression effect.

A cadmium sulfide (CdS) photoconductive detector, prepared by introducing a trace of iodine impurity, typically has 500 times faster response on decay and 200 times faster response on rise than the standard CdS:Cl:Cu crystals. This crystal is used for detecting

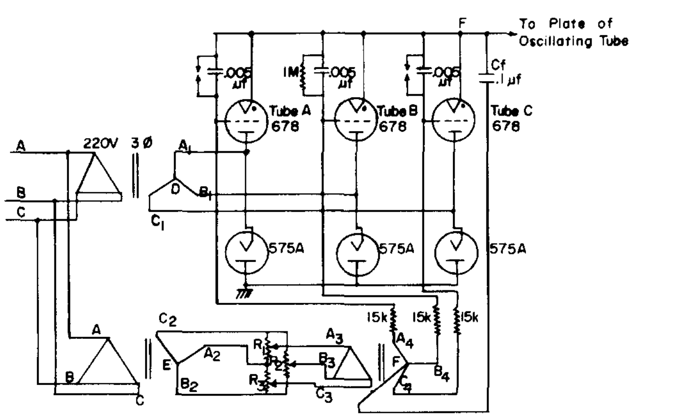


FIG. 1. Manual power control circuit of the Lepel T10-3KC induction furnace.

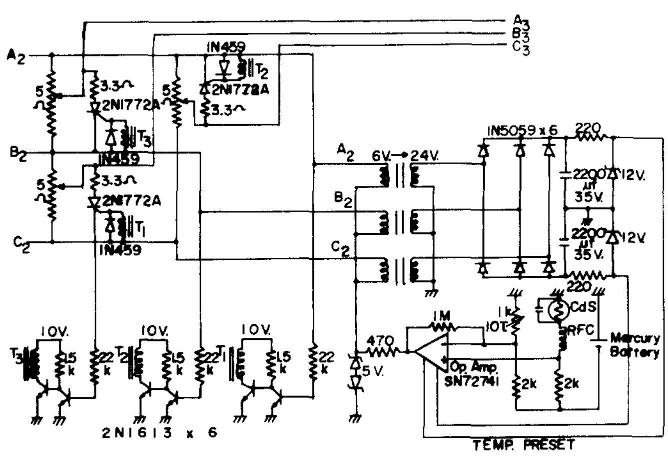


FIG. 2. Schematic of the automatic temperature controller for the Lepel T10-3KC.

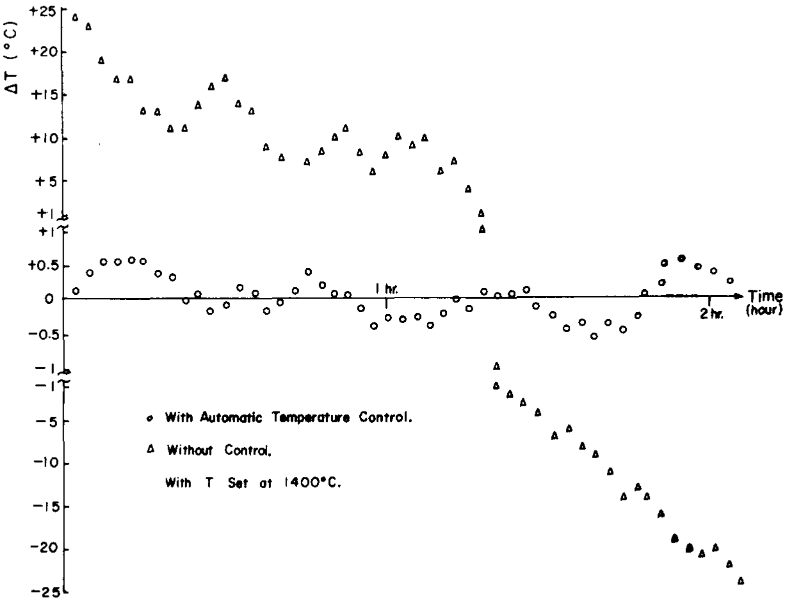


FIG. 3. Temperature fluctuations of the rf generator for 2 h of operation with and without automatic temperature control.

the temperature change of the oven. The spectral response covers the visible light and has a sharp cutoff wavelength at 8000 Å. Its surface-excited photoconductivity ($\lambda < 5100$ Å) is strongly temperature dependent, whereas the volume-excited photoconductivity ($\lambda > 5100$ Å) is practically temperature independent.[1] We use an $Al_2O_3$ single crystal rod for the light guide to the CdS detector.[2,3] The signal from the CdS detector is also fed to a digital voltmeter HP-3460B and then to a HP P-76562A recorder to monitor the temperature of the oven.

Figure 3 shows the temperature fluctuations of the rf generator for 2 h of operation with and without automatic temperature control. With automatic control, the drift of the temperature does not exceed ±0.4°C; while without automatic control, the drift is greater than ±25°C.

* This work supported by the Chinese National Science Council.

[1] R. H. Bube, *Photoelectronic Materials and Devices*, edited by S. Larach (Van Nostrand/Reinhold, New York, 1965), p. 129.
[2] I. E. Compbell, *High Temperature Technology* (Wiley, New York, 1956), p. 58.
[3] A. I. Dahl, *Temperature—Its Measurement and Control in Science and Industry* (Reinhold, New York, 1962), Vol. 3, Part 2, p. 396.